Area-wide management of insecticide resistant pests of cotton in India

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ABSTRACT

Serious insecticide resistance has been demonstrated in a number of major pests of cotton in India since the late 1970s. This position has increasingly compromised the ability of farmers to undertake economic pest control. Work at a range of Indian and international institutions in the 1990s laid the foundations for rationalized pesticide use taking account of the potential contributions of proper targeting and timing of pest control, the role of beneficial organisms and the pattern of insecticide resistance and cross resistance across the country. By 2001 this had been demonstrated to provide environmental, human health and financial benefits to thousands of farmers across four Indian states. The program was expanded from 2002 under Government of India, Cotton Technology Mission funding, to cover the twenty districts having the heaviest cotton insecticide use in the ten major cotton producing states of the Indian union. The average number of insecticide applications per season across the participating farmers in the eight states from which data is currently available, fell 56% from 7 to 3.1 applications. Cotton yields increased on average by 12% while net profitability increased by $77/ha (an average state percent profitability increase of 85% across the eight states). In addition, resistance to the pyrethroid, cypermethrin, in the area following the program for longest (the Wardha district of Maharashtra) fell between 1996 and 2002 from a resistance factor (RF) of 96 to RF 9. That of endosulfan fell from RF 29 to RF 1. The program is set to double the number of participating villages and greatly increase the number of farmers in 2003-4.

Introduction

Insecticide resistance is a major problem in Indian cotton production. Insecticides account for over 40% of the variable costs of production but the efficacy of the most widely used materials is severely compromised for a range of the major pest species, with cotton bollworm, *Helicoverpa armigera* (Hübner), of most concern for many years now (Armes *et al.,* 1992 and 1994). The recent resistance situation for *H. armigera* in India is described in Kranthi *et al.* (2001a, b; 2002b). Additional information for the pink bollworm (*Pectinophora gossypiella* (Saunders)), the spotted bollworm (*Earias vitella* (Fab.)), the cotton leafworm (*Spodoptera litura* (Fab.)) and the whitefly (*Bemisia tabaci* (Gennadius)) are given in Kranthi *et al.* (2002a) and a generalized picture of the resistance position for each species in the three main cotton production zones is given in Russell *et al.* (2000).

With newer plant protection chemistries still expensive in India, and effective, affordable and available biological products not generally accessible to small farmers, managing the resistant insects has become a cotton sector priority and much work has been undertaken to understand the patterns of resistance and its underlying mechanisms (Kranthi, 1998; Kranthi *et al*., 2001a, b). However, resistance management is only of interest to the individual small farmer if it also delivers timely and affordable pest control. From 1993 onwards, a concerted effort has been made to provide such packages of practice, under a variety of funding and with a range of partners.

Armes *et al*. (1995), Russell *et al.* (1998 and 2000) and Kranthi *et al.* (this volume) describe the process by which the current resistant insect management strategy evolved and its success at the research and field trial level. By 1998-99, demonstrations across 23 villages (1,650 farms) in the four states of Tamil Nadu, Andhra Pradesh, Maharashtra and Punjab were showing regional average pesticide application reductions of 29-92%, yield increases of 17-70% and reductions in human health risk of 48-92%. Average profitability increases ranged from US $40/ha to US $226/ha (Russell *et al.,* 2000) turning a very marginal economic activity into a significantly profitable one. The Indian Council for Agricultural Research built on these results with village adoption projects in Haryana, Maharashtra, Andhra Pradesh and Tamil Nadu in the 1999-2000 and 2000-2001 seasons with 1-10 villages per state/season and some 2,500 farmers participating each year. These obtained pesticide reduction and yield increases comparable to those in the earlier work (Figures 1 and 2). These results encouraged the Indian Government to support a much large project to expand the benefit from this work to the 20 cotton districts, which between them were responsible for 80% of all insecticide use on cotton in India. These districts were:

North Zone (Haryana, Punjab, Rajisthan and Orissa): Sirsa, Hissar, Fatehabad, Hanumangarh, Sriganganagar, Bhavanipatnam, Bhatinda, Mansa and Abohar.

Central Zone (Maharashtra, Madhya Pradesh, Gujarat): Wardha, Parbhani, Hingoli, Yeotmal, Amaravati, Surendranagar, Baroda, Chindwara and Khandwa.

South Zone (Andhra Pradesh, Karnataka and Tamil Nadu): Guntur, Kurnool, Adilabad, Warangal, Prakasam, Coimbatore, Belgaon and Haveli.

This was funded from the 2002-2003 season from Cotton Technology Mission funds (Mini-Mission II), with c. US $185,000 for each of the first two seasons.

Experimental procedure

Project structure

In order to position the program for expansion across the country, a national structure was set up, with the Indian Union Agricultural Commissioner, the Plant Protection Adviser to the Government of India and the Secretary of the Department of Agricultural Research and Extension as part of the monitoring committee along with the Director of the Central Institute for Cotton Research. The practical work of implementation was undertaken by state level co-ordinators, supervised by a national implementation committee (Figure 3). Based on the findings of earlier work, the technical leadership was felt to be best focused within the Agricultural Universities and research institutions that had the greatest involvement in and enthusiasm for cotton IPM work. Table 1 lists these technical leadership partners for the states. At the state level, a co-ordinator was appointed for each of the 26 cotton districts of the program. A bollworm resistance monitoring lab with two staff was set up in each district and field co-ordinators appointed. These were responsible for programs in 10 villages (in 2002-3) in each district. Full-time IRM facilitators were appointed from within the local farming communities, approximately one per two villages in the program. These facilitators then worked directly with the cotton farmers to familiarise them with appropriate IPM practices for their area (including suitable varieties, agronomy, identification of pests and beneficial insects, scouting systems, criteria for pest management decisions, and spray application practices). Technical back-stopping was provided by the staff of the Central Institute for Cotton Research who had been involved with the development of the program from its inception. As with previous phases of the work, this was run on a village participatory basis, with village level discussion on what problems were faced and what solutions were practicable, preceding the agreement of the village farmers to participate in the program. As representatives of the village, a limited number of growers (but not less than 10) pursue the program in the first year, demonstrating progress to their fellow farmers throughout the season. Experience shows that a much higher proportion of farmers involve themselves in subsequent seasons. In each district the number of villages will be doubled in 2004-5 and it is hoped that the participation per village will increase ten fold, taking the number of participating farmers to c. 50,000.

IPM/IRM practices

The practices promoted are described in Russell *et al.* (1998, 2000), Kranthi (1999) and Kranthi *et al.* (this volume). They vary according to the cotton zone, planting types and date sequence of pests. In practice, the process of considering appropriate practices, identifying pests and thinking about rational control are probably more important to farmers in gaining the benefits reported, than the precise thresholds or materials used. In summary, farmers were trained and supported in the implementation of the following components.

Cotton varieties

Certified cotton varieties, tolerant to sucking pests and cotton leaf curl virus (north zone).

Agronomy

Early planting; adequate spacing (varies with varieties/hybrids/soil and water conditions); fertilizer use (soil testing where available); irrigation used to control excessive vegetative growth (in north).

Pest scouting

A weekly 20 plant sample is examined by the farmer using the provided random sampling plan. Jassid and aphid control was only considered when 10 plants out of the 20 plant sample were showing curling damage to the top four leaves. *Earias* spp. damage by shoot tip burrowing was considered a problem only if three plants per 20 examined showed fresh damage. The early season bollworm intervention threshold was one larva or fresh damaged fruiting structure per two plants examined. Later this is relaxed to one larva or fresh damaged boll per plant. Pink bollworm tends to be a late season pest and a threshold of 10% of bolls damaged was the chosen intervention threshold (in practice few farmers will regularly cut open apparently undamaged bolls). These bollworm thresholds are relaxed by the standards of much of the cotton producing world, but are born of experience with the level of yield loss tolerable to small farmers, bearing in mind their severe financial constraints and the harmful effects of heavy spraying of insecticides on other components of the cotton ecosystem.

Insecticide use

The effective availability of chemistries is limited by cost to pyrethroids, organophosphates, endosulfan and the carbamate methomyl, although imidacloprid for sucking pest control and spinosad and indoxacarb for bollworm control are becoming more widespread, in part in response to the resistance problem with the older chemicals. A level of functional cross-resistance exists between pyrethroids and the carbamate and between the organophosphates and endosulfan. Where possible these were not placed next to each other in chemical management strategies. Rotation of active groups was recommended but effectiveness against the pest complex at the particular time of the season was important, as was avoiding early season applications and delaying the use of the broadest spectrum materials (especially the pyrethroids) until as late as possible in the season. Pyrethroids still have reasonable efficacy against pink, spotted and spiny bollworms although their efficacy against *H. armigera* is severely compromised. Where tolerant germplasm was not utilized, imidacloprid was recommended as a seed treatment for early season sucking pests. Foliar use was discouraged.

For simplicity's sake the following window strategy was employed in recommending bollworm insecticides.

Window 1: *Vegetative and early reproductive stage* (60-90 days after plant emergence)
Aim: To suppress the first generation of *H. armigera* while minimizing the effect on beneficial insects
Scouting: ETL 0.5 larvae/plant
Materials: Neem/HaNPV if good quality material is available at reasonable prices. Endosulfan (relatively soft on some beneficials and resistance levels are lowest in the early season (Aug/Sept).

Window 2: *Mid-reproductive stage (90-110 days)*
Aim: To protect boll formation by controlling the mixed instars of overlapping *H. armigera* generations.
Scouting: ETL 1 larva per plant
Materials: Organophosphates and carbamates (specified) (resistance is low to moderate for quinalphos, chlorpyriphos and profenophos). Avoiding early season use helps prevent unnecessary disruption of beneficial insects, as does the complete avoidance of monocrotophos and acephate.

Window 3: *Peak fruiting phase (110-130 days)*
Aim: To control *P.gossypiella* and *Earias* spp. as well as later generations of *H. armigera*
Scouting: ETL - 1 larva per plant
Materials: Pyrethroids. (Still effective on pink and spotted/spiny bollworms). Avoiding early season use as it disrupts beneficials. High *H. armigera* resistance may be synergised with ethion, quinalphos or chlorpyrifos mixed with the pyrethroid.

Farmers were provided at cost (c. US$0.30) with local language versions of a color IRM/IPM brochure (Kranthi, 1999).

Results

Of the 10 states initially agreeing to participate in the program, only the smallest producer, Orissa, failed to put an appropriate management structure in place and so did not successfully implement the program in the first field season. Zonal training programs were run for state and district level organizers. These organizers in turn ran training programs for the program field staff. 3,519 farms were run on the program lines in 260 villages in 2002-3 (Figure 4). Fifteen district level insecticide resistance monitoring laboratories operated effectively during this first field season. Punjab state has yet to report its results and the subsequent figures are therefore for the eight states reporting to date.

Reported insecticide use across participating farmers in the eight states is shown in Figure 5, with an average 56% reduction in the number of applications from 7 to 3.1. Bollworm pressure was higher in the northern states (and especially the irrigated areas) and insecticide use amongst control farmers and the program farmers was higher there. Every state showed substantial insecticide use reductions. This did not come at the expense of cotton yields, which were as good as, or better than, those of non-participators in all states (figure 6) with an average improvement of 12 percent across all states. Net profitability was affected by the reduction in the value of pest management inputs and the yield advantages. It is not possible, within the data collected, to distinguish that component of yield advantage, which may be due to improved varieties and agronomy from that due to the improved pest management. Average profitability rose in all states, with Maharashtran farmers moving into profit from loss (figure 7). On average, the net increase in profitability was US $77/ha. The average percentage increase in profitability across the eight states was 85%, with Haryana the lowest at 11% and Mararashtra the highest at 225% (non-participating farmers made a loss).

Given the highly mobile nature of *H. armigera* adults, it was not clear whether implementation of this program over modest areas could be expected to directly affect insecticide resistance levels in these areas. Table 2 shows the change in resistance levels to examples of the four major chemical groups used, in the Wardha district of Maharashtra, the area undertaking the program continuously for longest. The 10 villages in the cluster covered an area of c. 30 km diameter. Farmer participation levels were >90% and insecticide use on cotton fell >90% as *Helicoverpa* pressure was generally low in these years. Resistance monitoring has been carried out regularly throughout the cotton season here since 1996. Organophosphate and carbamate resistance had been very low before the beginning of the IRM/IPM program in 1996 and remained negligible. Cypermethrin had been the most commonly used chemical and the resistance frequency, at RF 96 was medium to high in 1996. By 1998 this had fallen to single digits and remained low through to 2002. Endosulfan resistance was medium in 1996 (RF29). This also dropped rapidly and has been negligible for the last two years. This restoration in the efficacy of the commonly used cotton insecticides is a further major benefit of the strategy. It will enable farmers to achieve adequate control with limited quantities of the cheaper insecticides. Insecticide resistance monitoring in the 15 centers, which had active programs in 2002 will be used as a baseline for expected changes in 2003-4 and beyond.

Conclusions

The implementation of improved agronomy and scouting-based pest management decision-making has demonstrated benefits in terms of reduced costs of production in all states in which it was tested. The profitability of cotton production was enhanced by an average of US $77/ha (range from US $49/ha in Haryana to US $164/ha in Gujarat). The reduced use of chemistry, and possibly the particular sequence of chemical use advocated, has, over a number of years resulted in sustained reductions in resistance by *H. armigera* to the most widely used chemicals in the area of the 10 contiguous villages in the Wardha district of Maharashtra. Data collection systems are in place, and the 2002-3 baseline data are available to test whether this result will be repeated nation-wide. The results to date have encouraged expansion of the Cotton Technology Mission funding to 20 villages in each district in 2003-4. It is now vital that the level of participation in each village is raised to encompass a majority of farmers (>100/village). If this can be accomplished, then the goal of achieving significantly increased profitability at a cost of less than US $5/season/farmer will be achieved and the prospects for self sustaining expansion and changes in nationwide pest management practices will be greatly enhanced.

Acknowledgements

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Table 1. Research organizations acting as technical implementation partners for the IPM/IRM program.

North India	
Punjab	Punjab Agricultural University
Haryana	Central Institute for Cotton Research, Sirsa
Rajisthan	Rajistan Agricultural University
Central India	
Maharashtra	Central Institute for Cotton Research, Nagpur
	Polytechnic, Wardha
	Marthwada Agricultural University
Myda Pradesh	J.Neru Krishi Viswa Vidyalay
Gujarat	Gujarat Agricultural University
South India	
Andhra Pradesh	Andhra Pradesh Agricultural University
Karnataka	University of Agricultural Science, Dharwad
Tamil Nadu	Central Institute for Cotton Research, Coimbatore
Orissa	Orissa University of Agriculture and Technology

Table 2. *Seasonal average for* H. armigera *resistance factors 1996-2002, Wardha district cluster of IRM villages, Maharashtra.*

	Season							
	1996 Status	1997 RF	1998 RF	1999 RF	2000 RF	2001 RF	2002 RF	2002 Status
Pyrethroid (Cypermethrin)	Medium	96	7	10	6	6	8	Low
Cyclodiene (Endosulfan)	Medium	29	35	7	5	1	1	None
OP (Quinalphos)	Low	2	3	1	1	1	1	None
Carbamate (Methomyl)	None	1	1	1	1	1	1	None

(Resistance Factor (RF) is the factor by which the LD50 of a susceptible population has to be multiplied to obtain the observed LD50 figure. A resistance status of medium implies that the field usefullness of the material is compormised. A status of low implies a measurable resistance in the laboratory but no detectable field control problem).

Figure 1. *Mean percentage reduction in the average number of insecticide applications per season for participators in the IPM/IRM programs compared with those of neighboring farmers. 1998-9 data from the DFID, Crop Protection Program project (with Punjab as the northern state). 1999-2001 season's data from the Indian Council for Agricultural Research project (with Haryana as the northern state).*

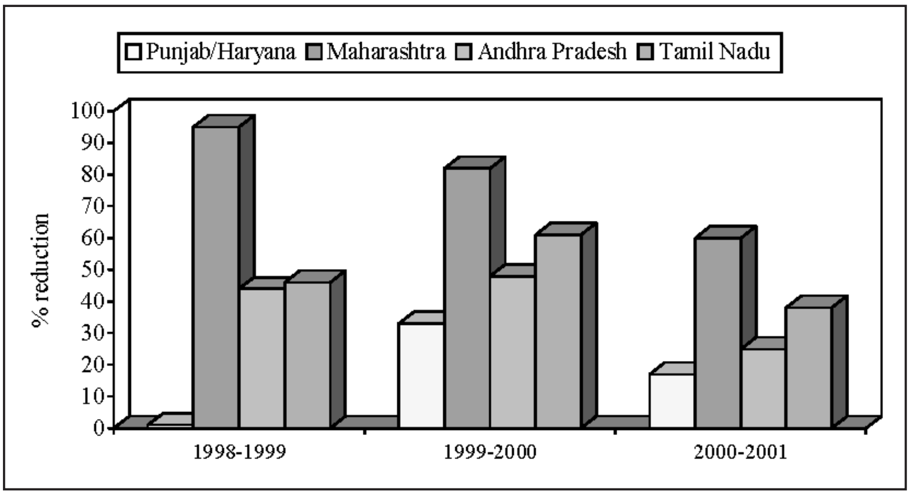
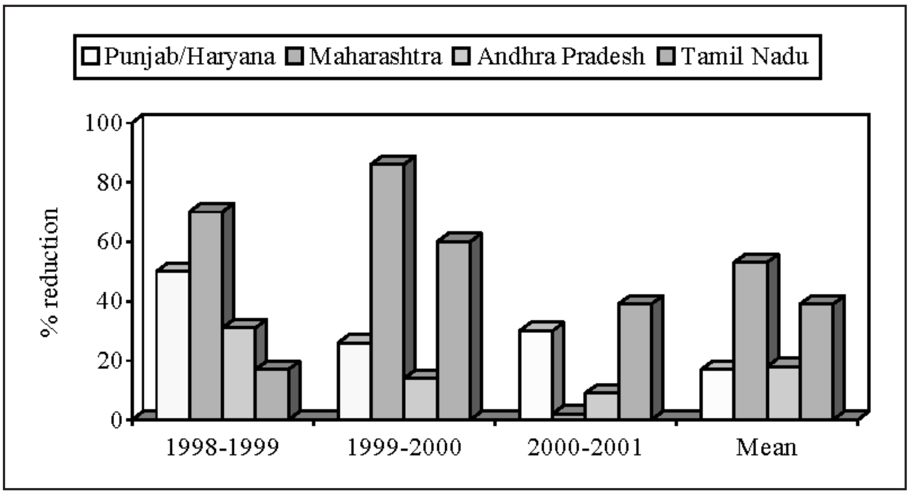


Figure 2. *Mean percentage increase in the seed cotton yield per unit area for participators in the IPM/IRM programs compared with those of neighboring farmers. 1998-9 data from the DFID, Crop Protection Program project (with Punjab as the northern state). 1999-2001 seasons Indian Council for Agricultural Research project (with Haryana as the northern state).*



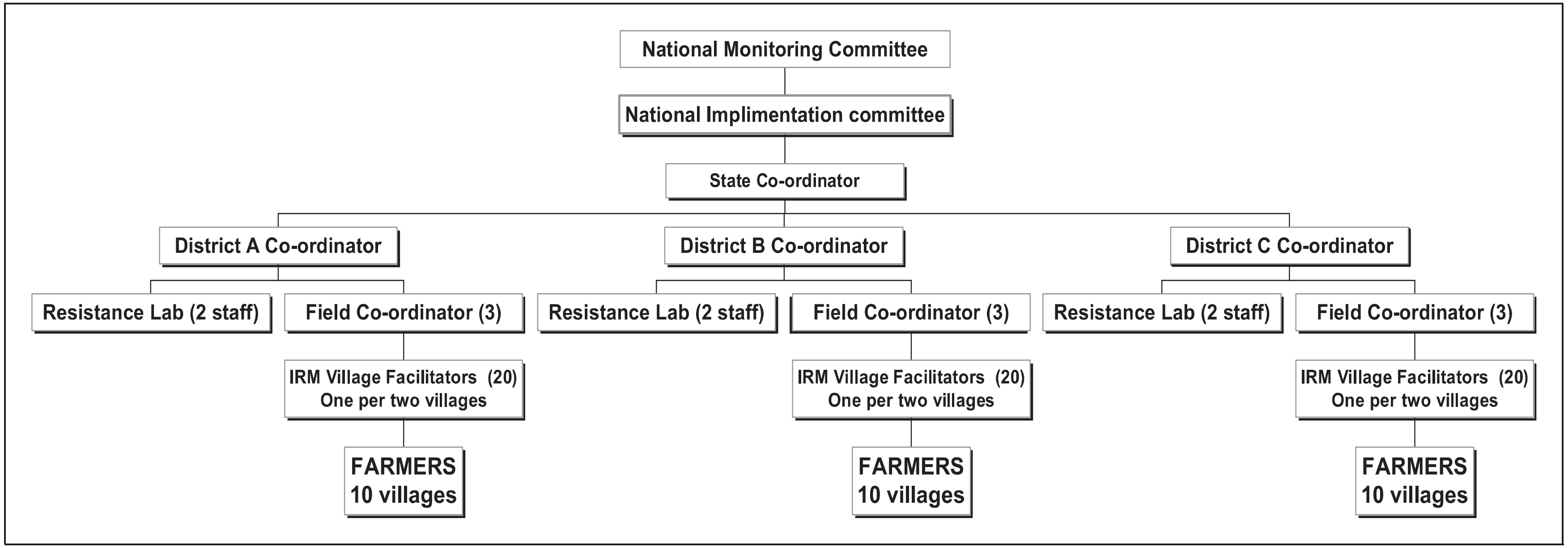


Figure 3. *Implementation structure for Cotton Technology Mission IPM/IRM village project 2002-4.*

Figure 4.
The main cotton growing regions of India (hatched) with the number of program farms in each of the nine major states in the 2002-3 season. Small numbers are the 23 resistance monitoring sites for the five major insect pests of cotton in 2001.

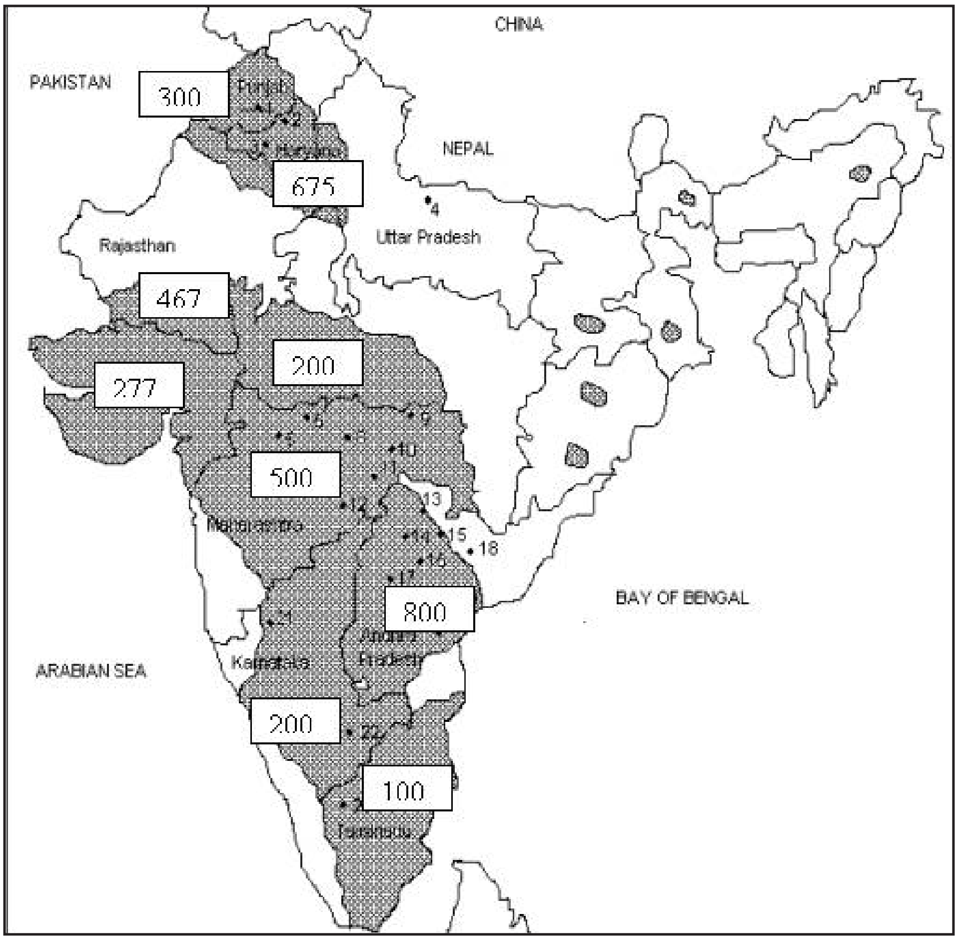


Figure 5.
Average number of insecticide applications applied during the 2002 cotton season by participation (IRM) farmers and those undertaking normal farmer practices (control farmers) (Northern states on the left, southern states on the right).

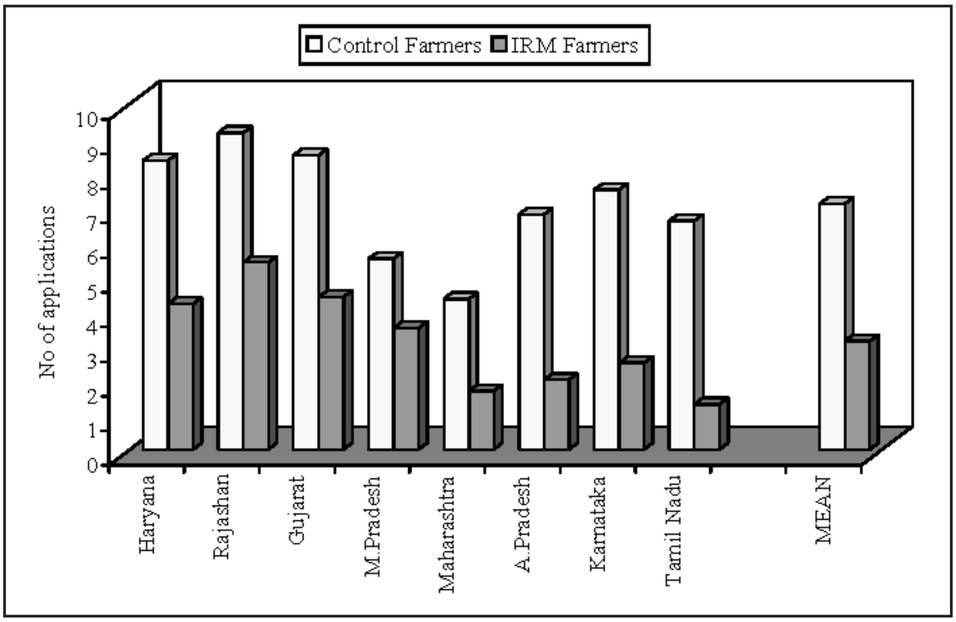


Figure 6. *Mean seed cotton yield (kg/ha) for IRM/IPM cotton farmers compared with those from farms in immediately neighboring villages in 2002-3 (Northern states on left, southern states on right).*

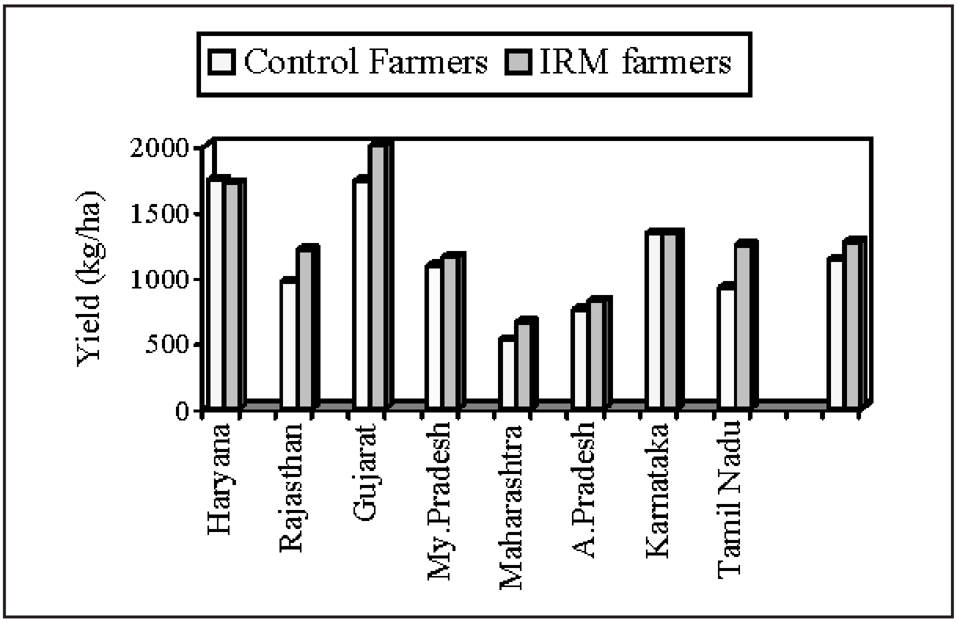


Figure 7. *Mean net income (US $/ha) for IRM/IPM cotton farmers compared with those from immediately adjacent villages, 2002-3 (Northern states on left, southern states on right).*